Fracture resistance and failure modes of endocrowns manufactured with different CAD/CAM materials under axial and lateral loading

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Abstract: OBJECTIVES The purpose of this in vitro study was to evaluate the fracture resistance and failure modes of endocrowns made of three computer-aided design/computer-aided manufacturing (CAD/CAM) materials subjected to thermo-mechanical cycling loading. MATERIALS AND METHODS Eighty mandibular molars were divided into four groups (n = 20): one (C E) was restored with lithium disilicate glass-ceramic conventional crowns, three were restored with endocrowns made of three different CAD/CAM materials; (E E) lithium disilicate glass-ceramic, (E V) zirconia-reinforced lithium silicate glass-ceramic, and (E C) resin nano-ceramic. After cycling loading, half of the samples from each group were loaded axially and the other half was loaded laterally. Fracture resistance was recorded in Newton (N) and failure modes were classified. Two-way ANOVA, Bonferroni post hoc (= .05), Chi-square, and multiple logistic regression tests were used to analyze data. RESULTS Statistically significant interaction were recorded between fracture resistance (N) and loading (P < .001), and groups (conventuional crown and endocrowns; P < .001). Endocrowns presented higher fracture strength than conventional crowns. Fracture resistance was significantly larger under axial loading. The numbers of irreparable failures were extremely important in the endocrowns groups (Groups E E, E V, E C), and only conventional crowns (Group C E) showed almost no irreparable failures under axial loading. CONCLUSION Lithium disilicate glass-ceramic recorded the highest fracture resistance under axial and lateral loading. CLINICAL SIGNIFICANCE The number of irreparable failures with all endocrown materials tested do not suggest yet the use of this type of restorations in posterior teeth.

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Fracture resistance and failure modes of endocrowns manufactured with different CAD/CAM materials under axial and lateral loading

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Abstract

Objectives: The purpose of this in vitro study was to evaluate the fracture resistance and failure modes of endocrowns made of three (CAD/CAM) materials subjected to thermo-mechanical cycling loading.

Materials and Methods: Eighty mandibular molars were divided into four groups ($n = 20$): one (C E) was restored with lithium disilicate glass-ceramic conventional crowns, three were restored with endocrowns made of three different CAD/CAM materials; (E E) lithium disilicate glass-ceramic, (E V) zirconia-reinforced lithium silicate glass-ceramic, and (E C) resin nano-ceramic. After cycling loading, half of the samples from each group were loaded axially and the other half were loaded laterally. Fracture resistance were recorded in Newton (N) and failure modes were classified. Two-way ANOVA, Bonferroni post-hoc ($\alpha = 0.05$), Chi-square, and multiple logistic regression tests were used to analyze data.

Results: Statistically significant interaction were recorded between fracture resistance (N) and loading ($P < 0.001$), and groups ($P < 0.001$). Endocrowns presented higher fracture strength than conventional crowns. Fracture resistance was significantly larger under axial loading. The numbers of irreparable failures were extremely important in the endocrowns groups (Group E E, E V, E C), and only conventional crowns (Group C E) showed almost no irreparable failures under axial loading.

Conclusion: Lithium disilicate glass-ceramic recorded the highest fracture resistance under axial and lateral loading .

Clinical Significance: The number of irreparable failures with all endocrown materials tested do not suggest yet the use of this type of restorations in posterior teeth .

KEYWORDS: Endocrown, CAD/CAM, fracture resistance, glass-ceramic, resin nano-ceramic, axial loading, lateral loading.

1 / INTRODUCTION

The rehabilitation of endodontically treated molars (ETM) with extensive coronal destruction remains a controversial topic in reconstructive dentistry.[1] The most frequent causes for diminution in fracture resistance of (ETM) are the wastage of tooth tissue accompanied with trauma, decay, existing restoration, and wide cavity preparation.[2] In addition, the desiccation and biomechanical changes in the dental tissues[3] result in restraining the sensory feedback during peak loads.[4] Selection of restoration designs and materials should be capable to substitute the loss of tooth structure in order to ensure esthetics, marginal seal, mechanical, and functional characteristics.[5,6] Many studies have notified that restoring ETM with posts can improve the retention of the overlying crowns,[7-9] but may weaken the residual teeth tissues and increase the risk for accidental root fracture.[8,9] Advances in adhesive systems, dental materials, and Computer-Aided Design / Computer-Aided Manufacturing (CAD/CAM) technologies[10-12] reduced the need of posts to restore the ETM and have resulted in new restoration design, which is more conservative and avoids failures of post space preparation like endocrown restoration.[13,14] Endocrown was proposed by Pissis in 1995,[15] it constructs the core structure and the crown as a monoblock restoration, covers the occlusal surface, and extents into the pulp chamber.[15,16] Endocrown uses the axial walls as macromechanical retention and the adhesive cementation as micromechanical retention.[15,16] Endocrowns are indicated in cases of short crown, limited interocclusal space, and sufficient tooth substance especially enamel.[17,18] They are also an alternative in cases of root complexes like calcification or curved shape.[19]

In comparison with the traditional treatment, all ceramic endocrowns have the advantages of good mechanical properties, high biocompatibility, good esthetics, preservation of the remaining tooth structure, and saving time.[10,20-22] The available literature has reported that molars restored with endocrowns had good clinical performance[23-28] and they showed higher fracture resistance than molars restored with fiber post and conventional crowns.[14,29,30] Some studies discussed the effect of different preparation shapes on the success of endocrown restorations like ferrule height[25,31] or pulp chamber extension.[26,28,32] Other studies discussed the effect of the materials factor: ceramic-based or resin-based.[11,21,24,33] Taking into consideration the influence of materials on the performance of endocrowns.[23] More researches are needed in order to help dentists selecting the appropriate materials, which have biomechanical properties similar to those of natural teeth.

The aim of this in vitro study was to evaluate the fracture resistance and failure modes of endocrowns using three different CAD/CAM materials: Lithium disilicate glass-ceramic (LDS), zirconia-reinforced lithium silicate glass-ceramic (ZLS), and resin nano-ceramic (RNC); and to compare the results with control group which were restored with glass fiber post, composite core and (LDS) crown, under axial and lateral loading. The two null hypotheses were (1) that the type of material, the type of restoration (conventional crown or endocrown) and the direction of load would not affect the fracture resistance; and (2) that the type of material, the type of restoration (conventional crown or endocrown) and the direction of load would not affect the failure modes.

2 / MATERIALS AND METHODS

This research was approved by an ethical committee. Eighty sound extracted mandibular molars with nearly similar size, free of decays or cracks, with complete roots and crowns morphology were chosen for this study. Teeth were preserved in 0,5% chloramine solution at 10°C. A standardized endodontic treatment was performed on all molars using NiTi rotary instrumentation

(ProTaper Universal; Dentsply Sirona, USA) and irrigation solution NaOCl (5.25%). The obturation of the root canals was performed with the hot condenser system B (Sybron Endo; Henry Schein, Inc, Germany), gutta percha (Calamus Dual; Dentsply Sirona, USA), and root canal sealer (AH 26; Dentsply Sirona, USA). Using cylindrical metallic molds and dental surveyor (Marathon-103; Seayang, Korea), each tooth was embedded vertically in auto-polymerizing acrylic resin (Fastray; Harry J. Bosworth Co, Skokie, USA), 2 mm below the cemento-enamel junction (CEJ) to simulate bone level. Specimens were separated into eight groups (n = 10) according to type of restorations, materials used, and direction of loading. This sample size showed a statistical power of 80% (G*Power 3.1.9.2).[33] The distribution of groups is listed in Figure 1. The materials used, types, brands, chemical compositions and modulus of elasticity[11,21,24,33] are listed in Table 1.

In the endocrown groups, flowable resin composite (G-ænial Universal Flo; GC Corp, Europe) was used to cover the undercut areas and fill the entrance of the canals. In the control groups and according to manufacturer's instructions; glass fiber posts (GC Fiber Post # 1.2 mm; GC Corp, Europe) were cemented in the distal root canals, using 37% phosphoric acid (GC Etching Gel; GC Corp, Europe), silane (G Multi-PRIMER; GC Corp, Europe), bonding agent (G-premio BOND; GC Corp, Europe), dual cure activator (DCA; GC Corp, Europe), and dual-cure adhesive resin cement (G-CEM LinkForce; GC Corp, Europe). Then, the cores were built up using the same bonding system and resin composite (G-ænial posterior; GC Corp, Europe).

A standardized teeth preparation for all groups was performed under water spray, with the help of dental lab parallel surveyor (Marathon-103; Seayang, Korea) and 8° tapered diamond bur (No.856; Intensiv SA, Switzerland). Conventional crown groups were prepared, with a 1 mm chamfer finish line at the CEJ, 2 mm ferrule, 2 mm occlusal reduction, and 8° axial wall inclination. Endocrown groups were prepared with alignment of the pulpal walls and reservation an occlusal convergence of 8°angled following the pulp chamber morphology. The pulpal floor was flattened keeping a preparation depth of 4 mm. All the internal angles were rounded and smoothened by polishing diamond bur (No.504; Intensiv SA, Switzerland).

Digital scanning was performed for all specimens using powder-free intraoral camera (TRIOS 3; 3 Shape A/S, Germany). Acquired data was saved as eighty standard tessellation language (STL) files and transferred to CAD software (2017; 3Shape Dental System, Germany), which was applying to make similar anatomy design of all restorations on the virtual models. These STL files and 14-size CAD/CAM blocks were utilized to mill all restorations, under wet processing with a 5-axis milling machine (Coritec 250i; Imes-Icore GmbH, Germany). IPS e.max CAD and Vita Suprinity blocks were subjected to crystallization firing (Vita Vacumat, 6000 M, Vita Zahnfabrik GmbH, Germany) to impart their final esthetic and mechanical properties, while Cerasmart blocks were finished utilizing GC polishing kit.

Before cementation, all restorations were fitted on their corresponding teeth, cleaned and dried. Following the suggestions of the manufacturer, 5% hydrofluoric acid gel (IPS Ceramic Etching Gel; Ivoclar Vivadent AG, USA) was applied on the intaglio surfaces of the restorations for 20 seconds on IPS e.max CAD and Vita Suprinity restorations, and for 60 seconds on Cerasmart restorations to create micromechanical retention, then the restorations were rinsed off with forceful water spray for 20 seconds. A thin layer of silane agent (G Multi-PRIMER; GC Corp, Europe) was applied and left for 60 seconds to create a durable chemical bond. The recipient teeth were etched by applying 37% phosphoric acid (GC Etchant Gel; GC Corp, Europe) for 30 seconds on the enamel tissue and for 15 seconds on the dentin tissue, rinsed and dried with forceful water spray for 20 seconds. The bonding agent (G-Premio BOND, GC Corp, Europe) was applied on the prepared teeth, left for 20 seconds, air dried for 5 seconds, and light cured (LITEX 680 A;

Dentamerica, Inc, USA) for 10 seconds. The restorations were lutted using the dual-cure adhesive resin cement (G-CEM LinkForce; GC Corp, Europe), all restorations were seated on the corresponding prepared teeth, followed by brief light curing for 1-2 seconds to remove the excess of cement, then each surface was photopolymerized for 40 seconds. Samples were kept in distilled water at 37°C.

All samples were thermocycled (Thermocycler; Willytec, Germany) between 5°C and 55°C for a total of 3000 cycles, transfer time between the 2 baths was 5 seconds and the dwell time at each bath was 30 seconds. Mechanical loading was performed simultaneously in a linear dual-axis chewing device (CS – 4.2; Mechatronik GmbH, Germany) in a range of 5 mm of vertical movement and 0,5 mm of lateral movement, by applying axial loading force of 50 N and a frequency of 1.6 Hz in the center of the occlusal surfaces, with a satinless steel ball (diameter of 4 mm) for 300,000 cycles.[34,35] Samples were examined after aging using the stereomicroscope (Amscope 3.5; Irvine, USA), all samples survived the chewing simulator. Universal testing machine (Treviolo; Matest Spa, Italy), with a 3-mm diameter stainless steel ball, at a cross-head speed of 0,5 mm/minute, was used to perform the fracture test. Half of the samples from each material were vertically loaded on the center of the occlusal surface (axial loading). While the other half were mounted in a metallic fixation device and loaded under lateral force on the interface tooth-restoration, parallel to the occlusal surface (lateral loading).[6,33] The maximum force of fracture was recorded in newton (N). All specimens were analyzed using a stereomicroscope (Amscope 3.5; Irvine, USA) and scanning electron microscope SEM (AIS 2100; Seron technologies, Inc, Korea) (Figure 2), the failure modes were classified according to the description in table 2.

Fracture resistance outcomes were normally distributed. Two-way ANOVA test was used to compare mean fracture resistance between the four study groups (conventional crown and endocrowns) by loading type (axial and lateral), followed by reporting of simple main effects for group and loading type since there was a significant interaction effect between the two factors. Bonferroni adjusted post-hoc tests were used to assess differences between the four groups. Chi-square tests were used to test the association between failure modes (repairable versus irreparable) and each of group and loading. Multiple logistic regression was used to model fracture mode as a multivariate outcome (types I–V) to assess the effects of group and loading simultaneously. Relative risk ratio, Robust standard error, 95% confidence interval and two –sided *P* values were reported. The IBM® SPSS® statistics 20.0 statistical package and Stata MP/13.0 were used to carry out all statistical analyses. Statistical significance was set at 0.05.

3 / RESULTS

Mean fracture resistance (N) levels ranged between 1347 (group C E) and 2914 (group E E) under axial loading and between 788 (group C E) and 1516 (group E E) under lateral loading (Table 3). There was a statistically significant interaction between fracture resistance and loading ($P < 0.001$). The simple main effects for loading were all statistically significant ($P < 0.001$; Table 3), fracture resistance being significantly larger under axial loading. Mean differences in fracture resistance (N) between axial and lateral loading ranged between 560 (Group C E) and 1542 (group E C).

The simple main effects for groups (conventional crown and endocrowns) were statistically significant under both axial and lateral loading ($P < 0.001$; Table 3). Under axial loading, the lowest fracture resistance was for Group C E then group E V ($P < 0.001$) and then groups E C and E E ($P < 0.001$) which were statistically similar to each other ($P = 0.395$). Under lateral loading, group C E displayed the lowest fracture resistance, then groups E V and E C ($P = 0.009$ and 0.001, respectively), then group E E ($P = 0.001$). Fracture resistance was similar for groups E V and E C ($P = 0.733$).

Overall, the majority of failures were repairable, except for the E E group. Under axial loading, failure modes III and V were predominant. Lateral loading resulted in a greater representation of all failure modes (Figure 3). The largest proportion of irreparable failures was present in Group E E under lateral loading (Figure 4). There was no statistically significant association between failure modes (repairable versus irreparable) and group (conventional crown and endocrowns) (Chi Square = 7.521; $P = 0.057$) or between failure modes and loading (Chi Square = 0.000; $P = 1.000$).

Multivariable analysis resulted in a statistically significant model for the effects of loading (axial and lateral) and group (conventional crown and endocrowns) on failure mode ($Chi_2 = 36.78$; $P = 0.002$; Table 4). The effect of loading was statistically significant only when comparing type IV to type III ($P = 0.044$; Table 4). When comparing lateral to axial loading, the relative risk of achieving type IV fracture compared to type III fracture increases by 1.9 times, if the group variable is kept constant (within each fixed group). On the other hand, the effect of group on fracture mode was statistically significant only when comparing type V to type III. If loading is kept constant, the likelihood that a type V fracture occurs compared to a Type III fracture is 2.00 times for Group E E than for Group C E ($P = 0.021$; Table 4).

4 / DISCUSSION

The purpose of this in vitro study was to evaluate the effect of group (conventional crown and endocrowns) and direction of loading on the fracture resistance and failure modes. According to the results of this study, the 2-null hypothesis could be rejected, because the effect of group and loading had a statistically significant effect on the fracture resistance, and had a statistically significant effect on the failure modes in selective comparisons.

Fiber post has similar biomechanical properties to that of dentine allowing better distribution of masticatory forces and reduce the risk of root fracture occurred with cast post,[9] But creating an adequate ferrule may require other intervention like crown lengthening, which may alter crown to root ratio and cause wastage of sound tooth tissue.[36] In addition, preparation of the endocrown conserves tooth structures,[37] because it has supragingival margins on peripheral enamel without root-canal preparation, enhancing bonding capacity and hygiene control.[20]

The clinically relevant factors are that human teeth were utilized in place of metallic or plastic specimens cause of their biomechanical and adhesive properties, epoxy resin was used to embed the roots of the teeth 2 mm below the CEJ to imitate the bone level, specimens were tested under axial and lateral loading to replicate all masticatory forces, thermomechanical cycling loading effects were also estimated, preparations were accomplished by one operator on dental lab parallel surveyor and precise CAD/CAM system was applied for scanning and milling.

The static loading test was accomplished by was applying axial force at an angle of 90° along the long axis,[33] because lateral forces are always accompanied with axial forces during chewing function.[38] The durability of endocrowns should be studied under compression and shear stresses, because the main reason for endocrowns failure is the adhesive failure.[6] However, the mean fracture forces for all studied samples were above the physiologic occlusal forces reported in the literature which vary from 200 to 900 N, and the exclusively lateral forces range in the order of 200 N.[38]

The fracture resistance results of this in vitro study showed statistically significant interaction between fracture resistance and loading ($P < 0.001$), and between fracture resistance and groups (conventional crown and endocrowns) ($P < 0.001$). It showed higher fracture resistance (N) for endocrowns (E E_{A} = 2914, E E_{L} = 1516) in comparison with conventional crowns supported on fiber posts and composite cores (C E_{A} = 1347, C E_{L} = 788). These results were in accordance with other studies,[14,29,30] which showed that ETT restored with endocrowns recorded higher fracture resistance than conventional ceramic crowns retained by posts and cores. These results can go back to the difference of construction between the two restorations, endocrown has a monobloc nature which can produce less internal pressures than the multi-interfacial nature of full crown retained by post and core, which has big number of adhesive interfaces between distinct materials (ceramic crown/resin core/post/dental tissue).[14,30] It can be explained too by the different occlusal thickness between the endocrowns and the conventional crowns.[39]Moreover, the endocrown preparation (Circumferential Butt Margin) allows the conservation of peripheral enamel, which is a key success in strong adhesion leading to better distribution of loading and high fracture resistance [40] .

The different materials used exposed an effect on the performance of endocrown restoration, the results of this study showed that under axial loading, ZLS had the lowest fracture resistance (N) (E V_{A} = 2279), while LDS material (E E_{A} = 2914) and RNC (E C_{A} = 2752) showed higher fracture resistance and were statistically similar. But under lateral loading, LDS material showed the highest fracture resistance (N) (E E_{L} = 1516), in comparison with RNC (E C_{L} = 1210) and ZLS (E V_{L} = 1074). These results can be explained by the good adhesive properties and high resistance to displacement of LDS ceramic because it is acid-etched; providing micromechanical interlocking with the resin cement, as well as adhesion between dental tissue and resin cement.[41] Moreover, the presence of crystalline particles in the LDS increases the fracture strength against loading.[42] On the other hand, the presence of zirconium oxide in ZLS decreases the bond strength with the dental surface and concentrates high stress at the endocrown-resin cement-tooth interface.[18]

The results of this in vitro study were in accordance with other studies,[19,33,43,44] which showed that LDS had the highest fracture strength, especially under lateral loading. Gresnight et al[33] assessed the fracture resistance of molar endocrown restorations made of LDS (IPS e.max CAD; Ivoclar Vivadent AG, USA) and RNC (Lava Ultimate; 3M ESPE, USA) under axial and lateral loading; they recorded no significance difference between LDS and RNC under axial loading (2675 and 2428 N) respectively, But LDS recorded higher fracture resistance than RNC under lateral loading (1118 and 838 N) respectively. Altier et al[43] evaluated the fracture resistance on molar endocrown restorations, using LDS (IPS e.max CAD; Ivoclar Vivadent AG, USA) and 2 kinds of RNC (Solidex; Shofu GmbH and Grandia; GC Corp, Europe) under axial loading; LDS recorded too higher fracture strength than RNC (3320, 2222, and 2366 N), for LDS, Solidex and Grandia respectively. Taha et al[44] presented that the fracture resistance of molar endocrowns made LDS (IPS e.max CAD; Ivoclar Vivadent AG, USA) and RNC (Cerasmart; GC Corp, Europe) were statistically insignificant (1478 and 1508 N, respectively), and was higher than ZLS (Celtra Duo; Dentsply, USA) (886 N). on the other hand, El Damanhoury et al[21] showed dissimilar results and reported higher fracture resistance for RNC (Lava Ultimate; 3M ESPE, USA) than LDS (IPS e.max CAD, Ivoclar Vivadent AG, USA) on molar endocrowns under lateral loading, (1583 and 1368 N) for RNC and LDS respectively.

The failure modes were analyzed using a stereomicroscope (Amscope 3.5; Irvine, USA) and SEM (AIS 2100; Seron technologies, Inc, Korea). They showed that under axial loading, the majority of failures were adhesive-cohesive (type III and V). But under lateral loading, all failure modes and the adhesive failure mode (type II) were presented too (Figure 3). The majority of failures were repairable (Figure 4), except for LDS (group E E) which had the largest proportion of irreparable failures, especially under lateral loading but at loads superior than recorded under masticatory function. These results were in agreement with other studies,[21,33,43] which were related to the difference in modulus of elasticity between the materials. The modulus of elasticity of RNC (20 GPa) and ZLS (70 GPa) give them a tendency to bend under loading and dispense strain more evenly. But LDS is more rigid and has a high modulus of elasticity (95 GPa), which concentrates strain in weak area and results in irreparable fractures.[12] Moreover, the lateral forces increase the irreparable fracture ratio, because the stresses are accumulated in the cervical area and don't spread along the long axis.[22] The effect of loading, or group (conventional crown and endocrowns) on the failure modes (repairable versus irreparable) was not statistically significant. The multivariable analysis was applied to evaluate the effect of group and loading simultaneously on the failure modes, it showed statistically significant effect in selective comparisons only, may be because of the limitation in the number of specimens (n = 10).

The multivariable analysis showed that if loading is kept constant, the likelihood that a type V (irreparable) fracture occurs compared to a Type III (reparable) fracture is 2.00 times for Group E E than for Group C E ($P = 0.021$; Table 4). This result can be related to the different preparation design and core build up material: cores of the C E group were built up with composite resin, following the shape of access cavity; while in the E E group, core was ceramic-based (Monobloc endocrown) which has higher modulus of elasticity and extended to 4 mm depth. Increasing the extension of the ceramic endocrown into the pulp chamber increase the adhesive surface and the fracture resistance, but diffuse strain to the root dentine running to irreparable failure. Hayes et al[32] presented that LDS endocrown with deeper pulp chamber depth (4 mm) recorded more irreparable failure than LDS endocrown with pulp chamber depth (2 mm), while the pulp chamber was partially built up with resin composite to leave 2 mm for the LDS endocrown. Furthermore, lateral loading focusses more pressure in the CEJ leading to irreparable failure.[22]

The direct comparison between studies is limited, the fracture strength and failure modes of endocrowns can be influenced by many factors such as: tooth preparation, restoration shape, materials used, loading technique (axial or lateral), artificial aging, method of fabrication, and luting method. However, this in vitro study didn't simulate all oral conditions, and has some limitations: The size of the groups was limited by 10 samples; three types of CAD/CAM materials were only tested; and artificial periodontium was not simulated.[45] Further in vivo studies, using more types of CAD/CAM materials with different preparation shapes, to test the clinical performance of the endocrown restorations.

5 / CONCLUSIONS

The following conclusions can be drawn from this in vitro study:

1- RNC or LDS and ZLS endocrowns showed higher fracture resistance than conventional ceramic crowns supported on fiber post and composite core. 2-Under axial loading, LDS endocrowns showed higher fracture strength than ZLS and no statistical difference with RNC. While LDS endocrowns showed the highest fracture resistance under lateral loading. 3- The number of irreparable fracture was extremely important in all endocrowns groups (between 30 and 70% of samples differently loaded) and for that other studies are desirable to solve this aspect before a wider clinical use of this type of restorations.

REFERENCES

1. Dietschi D, Duc O, Krejci I, et al. Biomechanical considerations for the restoration of endodontically treated teeth: a systematic review of the literature--Part 1. Composition and micro- and macrostructure alterations. Quintessence Int. 2007;38(9):733-43.

2. Reeh ES, Douglas WH, Messer HH. Stiffness of endodontically-treated teeth related to restoration technique. J Dent Res. 1989;68(11):1540-4.

3. Papa J, Cain C, Messer HH. Moisture content of vital vs endodontically treated teeth. Endod Dent Traumatol. 1994;10(2):91-3.

4. Heling I, Gorfil C, Slutzky H, et al. Endodontic failure caused by inadequate restorative procedures: review and treatment recommendations. J Prosthet Dent. 2002;87(6):674-8.

5. Faria AC, Rodrigues RC, de Almeida Antunes RP, et al. Endodontically treated teeth: characteristics and considerations to restore them. J Prosthodont Res. 2011;55(2):69-74.

6. Bindl A, Richter B, Mormann WH. Survival of ceramic computer-aided design/manufacturing crowns bonded to preparations with reduced macroretention geometry. Int J Prosthodont. 2005;18(3):219-24.

7. Zarow M, Devoto W, Saracinelli M. Reconstruction of endodontically treated posterior teeth--with or without post? Guidelines for the dental practitioner. Eur J Esthet Dent. 2009;4(4):312-27.

8. Soares CJ, Valdivia AD, da Silva GR, et al. Longitudinal clinical evaluation of post systems: a literature review. Braz Dent J. 2012;23(2):135-740.

9. Sarkis-Onofre R, Jacinto RC, Boscato N, et al. Cast metal vs. glass fibre posts: a randomized controlled trial with up to 3 years of follow up. J Dent. 2014;42(5):582-7.

10. Fages M, Raynal J, Tramini P, et al. Chairside Computer-Aided Design/Computer-Aided Manufacture all-ceramic crown and endocrown restorations: A 7-Year Survival Rate Study. Int J Prosthodont. 2017;30(6):556-60.

11. Gulec L, Ulusoy N. Effect of Endocrown restorations with different CAD/CAM materials: 3D finite element and weibull analyses. Biomed Res Int. 2017;2017:5638683.

12. Magne P, Schlichting LH, Maia HP, et al. In vitro fatigue resistance of CAD/CAM composite resin and ceramic posterior occlusal veneers. J Prosthet Dent. 2010;104(3):149-57.

13. Schmitter M, Hamadi K, Rammelsberg P. Survival of two post systems-five-year results of a randomized clinical trial. Quintessence Int. 2011;42(10):843-50.

14. Dejak B, Mlotkowski A. 3D-Finite element analysis of molars restored with endocrowns and posts during masticatory simulation. Dent Mater. 2013;29(12):e309-17.

15. Pissis P. Fabrication of a metal-free ceramic restoration utilizing the monobloc technique. Pract Periodontics Aesthet Dent. 1995;7(5):83-94.

16. Bindl A, Mormann WH. Clinical evaluation of adhesively placed Cerec endo-crowns after 2 years--preliminary results. J Adhes Dent. 1999;1(3):255-65.

17. Biacchi GR, Mello B, Basting RT. The endocrown: an alternative approach for restoring extensively damaged molars. J Esthet Restor Dent. 2013;25(6):383-90.

18. Zarone F, Sorrentino R, Apicella D, et al. Evaluation of the biomechanical behavior of maxillary central incisors restored by means of endocrowns compared to a natural tooth: a 3D static linear finite elements analysis. Dent Mater. 2006;22(11):1035-44.

19. Bankoglu Gungor M, Turhan Bal B, Yilmaz H, et al. Fracture strength of CAD/CAM fabricated lithium disilicate and resin nano ceramic restorations used for endodontically treated teeth. Dent Mater J. 2017;36(2):135-41.

20. Sevimli G, Cengiz S, Oruc MS. Endocrowns: review. J Istanb Univ Fac Dent. 2015;49(2):57-63.

21. El-Damanhoury HM, Haj-Ali RN, Platt JA. Fracture resistance and microleakage of endocrowns utilizing three CAD-CAM blocks. Oper Dent. 2015;40(2):201-10.

22. Kanat-Erturk B, Saridag S, Koseler E, et al. Fracture strengths of endocrown restorations fabricated with different preparation depths and CAD/CAM materials. Dent Mater J. 2018;37(2):256-65.

23. Sedrez-Porto JA, Rosa WL, da Silva AF, et al. Endocrown restorations: A systematic review and meta-analysis. J Dent. 2016;52:8-14.

24. Aktas G, Yerlikaya H, Akca K. Mechanical failure of endocrowns manufactured with different ceramic materials: An in vitro biomechanical study. J Prosthodont. 2018;27(4):340-6.

25. Taha D, Spintzyk S, Schille C, et al. Fracture resistance and failure modes of polymer infiltrated ceramic endocrown restorations with variations in margin design and occlusal thickness. J Prosthodont Res. 2017.

26. Dartora NR, de Conto Ferreira MB, Moris ICM, et al. Effect of intracoronal depth of teeth restored with endocrowns on fracture resistance: In vitro and 3-dimensional finite element analysis. J Endod. 2018.

27. Skalskyi V, Makeev V, Stankevych O, et al. Features of fracture of prosthetic tooth-endocrown constructions by means of acoustic emission analysis. Dent Mater. 2018;34(3):e46-e55.

28. Tribst JPM, Dal Piva AMO, Madruga CFL, et al. Endocrown restorations: Influence of dental remnant and restorative material on stress distribution. Dent Mater. 2018.

29. Helal MA, Wang Z. Biomechanical assessment of restored mandibular molar by endocrown in comparison to a glass fiber post-retained conventional crown: 3D finite element analysis. J Prosthodont. 2017.

30. Biacchi GR, Basting RT. Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns. Oper Dent. 2012;37(2):130-6.

31. Einhorn M, DuVall N, Wajdowicz M, et al. Preparation ferrule design effect on endocrown failure resistance. J Prosthodont. 2017.

32. Hayes A, Duvall N, Wajdowicz M, et al. Effect of endocrown pulp chamber extension depth on molar fracture resistance. Oper Dent. 2017;42(3):327-34.

33. Gresnigt MM, Ozcan M, van den Houten ML, et al. Fracture strength, failure type and Weibull characteristics of lithium disilicate and multiphase resin composite endocrowns under axial and lateral forces. Dent Mater. 2016;32(5):607-14.

34. Rocca GT, Daher R, Saratti CM, et al. Restoration of severely damaged endodontically treated premolars: The influence of the endo-core length on marginal integrity and fatigue resistance of lithium disilicate CAD-CAM ceramic endocrowns. J Dent. 2018;68:41-50.

35. Rocca GT, Sedlakova P, Saratti CM, et al. Fatigue behavior of resin-modified monolithic CAD-CAM RNC crowns and endocrowns. Dent Mater. 2016;32(12):e338-e50.

36. Tezvergil A, Lassila LV, Vallittu PK. Strength of adhesive-bonded fiber-reinforced composites to enamel and dentin substrates. J Adhes Dent. 2003;5(4):301-11.

37. Belleflamme MM, Geerts SO, Louwette MM, et al. No post-no core approach to restore severely damaged posterior teeth: An up to 10-year retrospective study of documented endocrown cases. J Dent. 2017;63:1-7.

38. Varga S, Spalj S, Lapter Varga M, et al. Maximum voluntary molar bite force in subjects with normal occlusion. Eur J Orthod. 2011;33(4):427-33.

39. Sasse M, Krummel A, Klosa K, et al. Influence of restoration thickness and dental bonding surface on the fracture resistance of full-coverage occlusal veneers made from lithium disilicate ceramic. Dent Mater. 2015;31(8):907-15.

40. Bedran-Russo A, Leme-Kraus A, Vidal C, et al. An overview of dental adhesive systems and the dynamic tooth-adhesive interface. Dent Clin North Am. 2017;61(4):713-731.

41. Kelly JR. Dental ceramics: what is this stuff anyway? J Am Dent Assoc. 2008;139 Suppl:4S-7S.

42. Della Bona A, Mecholsky JJ, Anusavice KJ. Fracture behavior of lithia disilicate- and leucite-based ceramics. Dent Mater. 2004;20(10):956-62.

43. Altier M, Erol F, Yildirim G, et al. Fracture resistance and failure modes of lithium disilicate or composite endocrowns. Niger J Clin Pract. 2018;21(7):821-6.

44. Taha D, Spintzyk S, Sabet A, et al. Assessment of marginal adaptation and fracture resistance of endocrown restorations utilizing different machinable blocks subjected to thermomechanical aging. J Esthet Restor Dent. 2018;30(4):319-328.

45. Heintze SD, Cavalleri A, Zellweger G, et al. Fracture frequency of all-ceramic crowns during dynamic loading in a chewing simulator using different loading and luting protocols. Dent Mater. 2008;24(10):1352-61.

Table 1 Material, Type, Brand, Chemical compositions and Modulus of elasticity

Material	Type	Manufacturer	Chemical composition	Modulus of Elasticity (GPa)
IPS e.max CAD	Lithium dissilicate glass-ceramic LDS	Ivoclar Vivadent United States	80 % SiO2, Li2 O, K2 O, P2 O5, ZrO2, ZnO, Al2 O3, MgO, Colouring oxides	95
Vita Suprinity	Zirconia reinforced lithium silicate glass-ceramic ZLS	VITA-Zahnfabrik Germany	60 % SiO2, 10 % ZrO2, 20 % Li2O, 10 % Pigments	70
Cerasmart	Resin nano-ceramic RNC	GC Dental Products Europe	Filler content: 71 %; SiO2, Baglass Resin matrix:29 %; Bis-MEPP, UDMA, DMA	20
GC Fiber post	Glass fiber post	GC Dental Products Europe	Glass fiber: 58% Resin matrix: 42%, methacrylate	20
G-ænial posterior	Light-cured restorative composite	GC Dental Products Europe	Filler content: 81%; Silicon dioxide, strontium glass Resin matrix: UDMA, TEGDMA, Bis-MEPP	14
G-ænial flo	Flowable composite	GC Dental Products Europe	Filler contant: 69%; Silicon dioxide, strontium glass Resin matrix: UDMA, TEGDMA, Bis-MEPP	10
G-CEM LinkForce	Dual-cure adhesive resin cement	GC Dental Products Europe	Fluoroaluminosilicate glass, 4 MET, phosphoric acid ester monomer, water, UDMA, DMA, silica powder, initiator, stabilizer.	8.3

Bis-MEPP: 2,2-bis (4-methacryloxyphenyl) propane, UDMA: urethane dimethacrylate, DMA: dimethacrylate, TEGDMA: triethylene glycol dimethacrylate, 4-MET: 4-methacryloyloxy ethoxycarbonyl phthalic acid.

Table 2 Classification of the failure modes

Type	Failure mode	Description	Prognosis
I	Cohesive failure	Fracture of the restoration (endocrown or conventional crown) without displacement (loss of adhesion)	Reparable
II	Adhesive failure	Debonding of the restoration (endocrown or conventional crown) without fracture	Reparable
III	Cohesive-adhesive failure	Fracture of the restoration (endocrown or conventional crown) with displacement (loss of adhesion)	Reparable
IV	Fracture of the restoration/tooth complex above the (CEJ)	Fracture of the restoration (endocrown or conventional crown) and the tooth or the composite build-up above the CEJ	Reparable
V	Fracture of the restoration/tooth complex below the (CEJ)	Fracture of the restoration (endocrown or conventional crown) and the tooth or the composite build-up below the CEJ, which require tooth extraction	Irreparable

Table 3 Distribution and simple main effects of group (material and preparation) and Loading type on fracture strength *(n = 80)*

Group		Axial		Lateral		Difference (A-L)			
		Mean	SD	Mean	SD	Mean	SE	F	P
C E		1347	185	788	92	560	87	41.545	<0.001**
E E		2914	205	1516	202	1399	87	259.563	<0.001**
E V		2279	290	1074	153	1205	87	192.832	<0.001**
E C		2752	242	1210	97	1542	87	315.727	<0.001**
2 Way ANOVA	F	131.605		24.264					
	P	<0.001**		<0.001**					
C E/E E		0.001**		0.001**					
C E/E V		0.001**		0.009**					
C E/E C		0.001**		0.001**					
E E/E V		0.001**		0.001**					
E E/E C		0.395		0.004**					
E V/E C		0.001**		0.733					

*Statistically significant, P < 0.05; **Statistically significant. P < 0.01

C E = Crown made of LDS e.max CAD, E E = Endocrwon made of LDS e.max CAD, E V = Endocrown made of Vita suprinity, E C = Endocrown made of Cerasmart.

Table 4 Multivariate analysis showing associations between failure mode (Types I-V) and the predictors Loading and Group (*n* = *80*)

Type	Associated variables	Relative Risk Ratio	Robust S.E.	95% CI	P-value
		Failure Mode ǂ			
I	**Loading** (Axial vs. Lateral)	1.41	0.9	[-0.35 ; 3.17]	0.118
	Group C E				
	E E	1.41	1.37	[-1.27 ; 4.08]	0.303
	E V	1.75	1.3	[-0.79 ; 4.29]	0.178
	E C	0.12	1.51	[-2.84 ; 3.07]	0.939
II	**Loading** (Axial vs. Lateral)	16.53	704.42	[-1364.11 ; 1397.19]	0.02*
	Group C E				
	E E	0.42	1.45	[-2.79 ; 2.88]	0.977
	E V	1.53	1.17	[-0.77 ; 3.82]	0.193
	E C	0.53	1.15	[-1.73; 2.79]	0.643
III	[Base Outcome]				
IV	**Loading** (Axial vs. Lateral)	1.91	0.94	[0.05 ; 3.76]	0.044*
	Group C E				
	E E	-0.67	1.29	[-3.19 ; 1.86]	0.605
	E V	-0.69	1.28	[-3.19 ; 1.82]	0.59
	E C	-1.27	1.25	[-3.72 ; 1.19]	0.312
V	**Loading** (Axial vs. Lateral)	1.04	0.6	[-0.14 ; 2.22]	0.083
	Group C E				
	E E	2.01	0.87	[0.3 ; 3.71]	0.021
	E V	1.3	0.9	[-0.46 ; 3.06]	0.147
	E C	0.81	0.87	[-0.88 ; 2.5]	0.35

(Base): refers to the base outcome all other categories are compared to; *Statistically significant, P < 0.05.

C E = Crown made of LDS e.max CAD, E E = Endocrwon made of LDS e.max CAD, E V = Endocrown made of Vita suprinity, E C = Endocrown made of Cerasmart.

Types of failure modes. Type I: Cohesive failure; Type II: Adhesive failure; Type III: Cohesive-adhesive failure; Type IV: Fracture of the restoration/tooth complex above the cemento-enamel junction (CEJ); Type V: Fracture of the restoration/tooth complex below the cemento-enamel junction (CEJ).

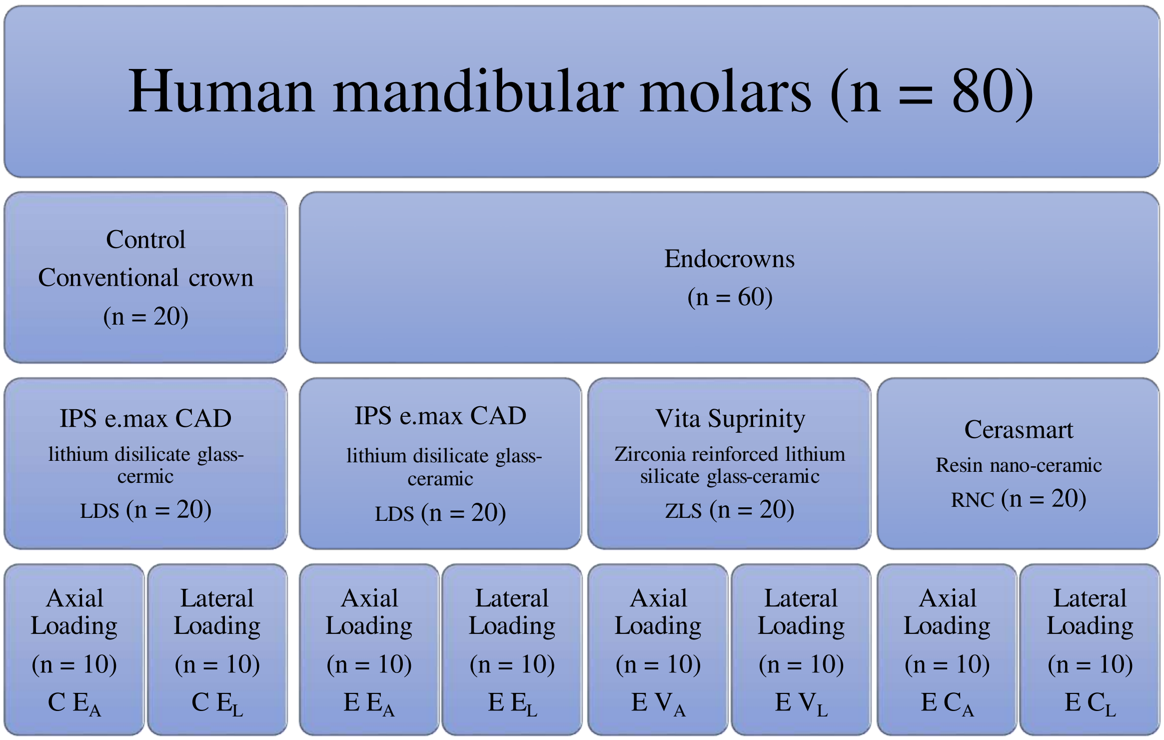

Figure 1 Distribution of groups according to preparations, materials used and directions of loading

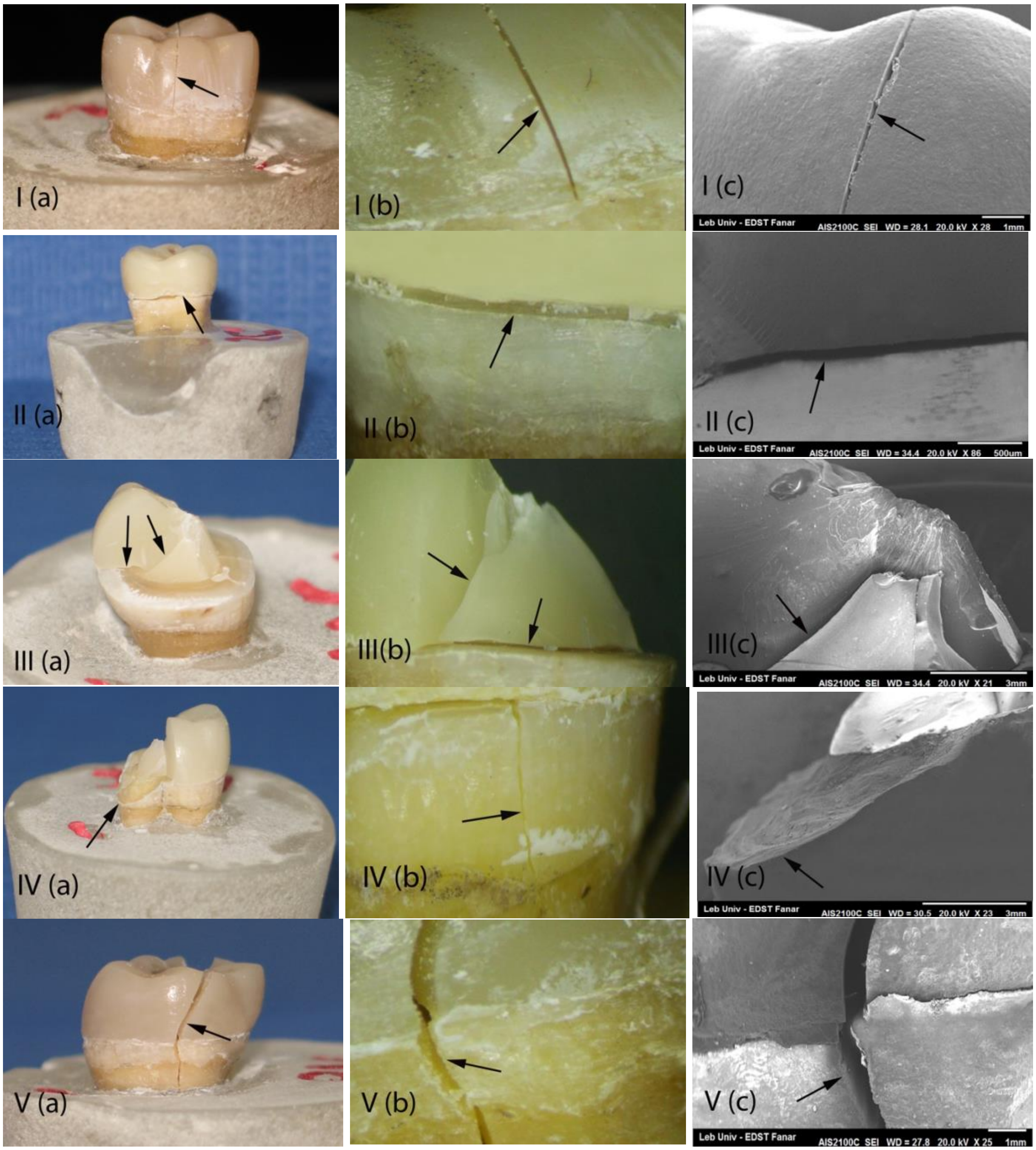

Figure 2. Camera photos (a), stereomicroscope (b), and scanning electron microscope SEM (c) of the 5 types of failure modes. Type I: Cohesive failure; Type II: Adhesive failure; Type III: Cohesive-adhesive failure; Type IV: Fracture of the restoration/tooth complex above the cemento-enamel junction (CEJ); Type V: Fracture of the restoration/tooth complex below the cemento-enamel junction (CEJ).

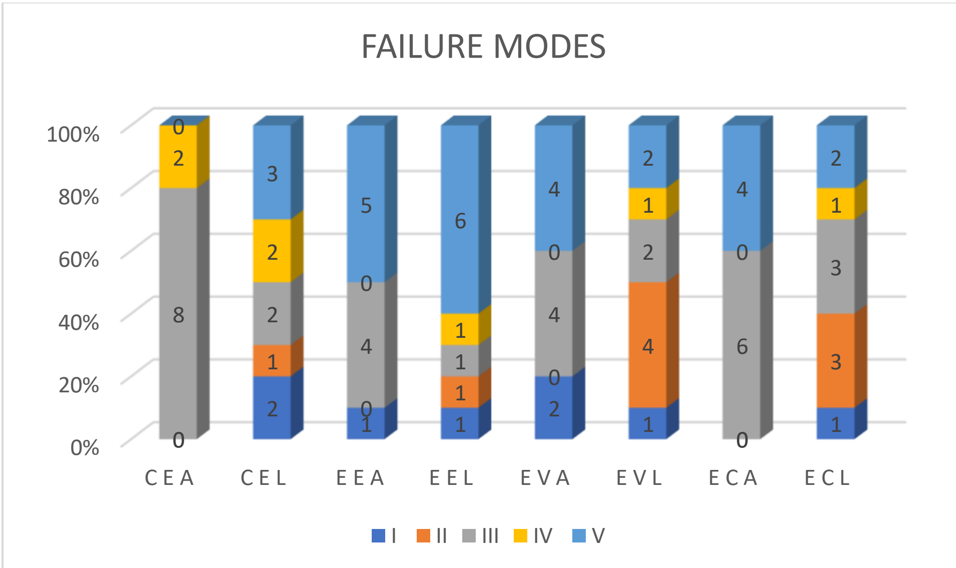

Figure 3 Frequencies of failure modes after axial and lateral loading. Type I: Cohesive failure; Type II: Adhesive failure; Type III: Cohesive-adhesive failure; Type IV: Fracture of the restoration/tooth complex above the cemento-enamel junction (CEJ); Type V: Fracture of the restoration/tooth complex below the cemento-enamel junction (CEJ).

C E A= **C**rown made of LDS **e**.max CAD tested under **A**xial load, C E L= **C**rown made of LDS **e**.max CAD tested under **L**ateral load, E E A = **E**ndocrwon made of LDS **e**.max CAD tested under **A**xial load, E E L= **E**ndocrwon made of LDS **e**.max CAD tested under **L**ateral load, E V A= **E**ndocrown made of **V**ita suprinity tested under **A**xial load, E V L= **E**ndocrown made of **V**ita suprinity tested under **L**ateral load, E C A= **E**ndocrown made of **C**erasmart tested under **A**xial load, E C L = **E**ndocrown made of **C**erasmart tested under **L**ateral load.

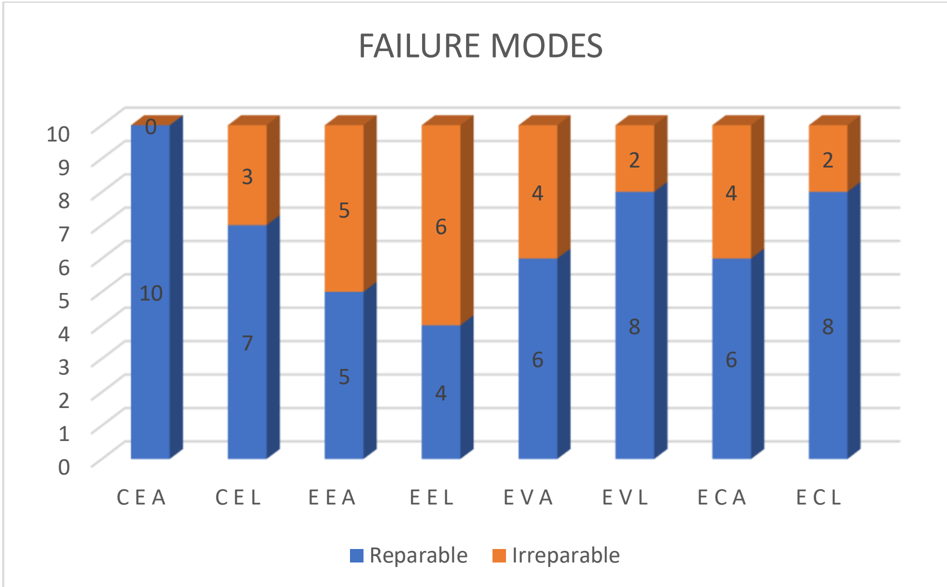

Figure 4 Frequencies of repairable and irreparable failure modes after axial and lateral loading. C E A= **C**rown made of LDS **e**.max CAD tested under **A**xial load, C E L= **C**rown made of LDS **e**.max CAD tested under **L**ateral load, E E A = **E**ndocrwon made of LDS **e**.max CAD tested under **A**xial load, E E L= **E**ndocrwon made of LDS **e**.max CAD tested under **L**ateral load, E V A= **E**ndocrown made of **V**ita suprinity tested under **A**xial load, E V L= **E**ndocrown made of **V**ita suprinity tested under **L**ateral load, E C A= **E**ndocrown made of **C**erasmart tested under **A**xial load, E C L = **E**ndocrown made of **C**erasmart tested under **L**ateral load.